Upper Hudson River PCB Modeling System Overview – Bioaccumulation Model

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Presented to
LimnoTech, Ann Arbor, MI

July 14, 2010

Bioaccumulation Model

- Model overview
- Theory and basic equations
- Application to the Hudson River
  - Spatial domain
  - Exposure inputs
  - Trophic structure and diet
  - Bioenergetics and toxicokinetics
- Calibration
- Validation

Model Overview

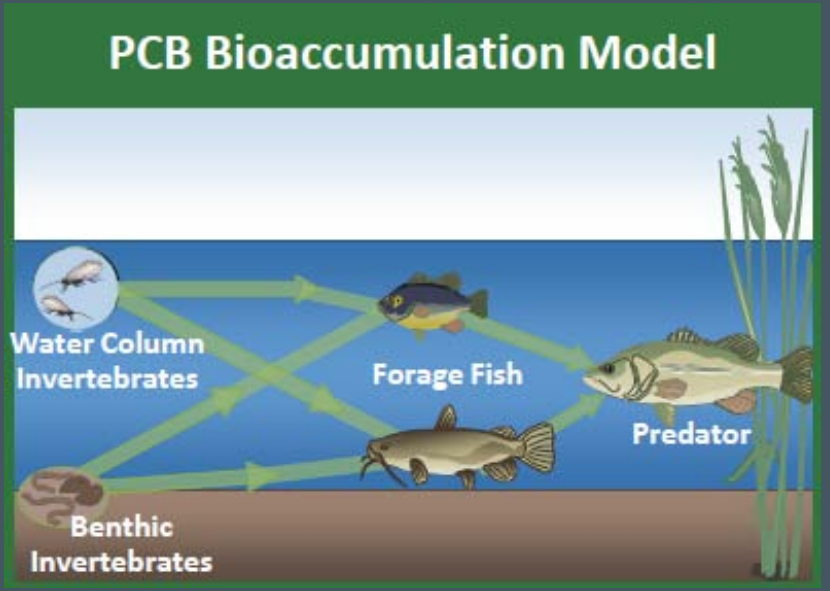
- Hudson River FDCHN
  - Modeling framework originally developed 30 years ago by Dr. John Connolly
  - Updated several times
  - Applied in a variety of aquatic systems
  - Published and presented numerous times

Table 1-1. Previous applications of the bioaccumulation model

System	Chemical	Food Web Leading to	Reference
Lake Michigan	PCBs	lake trout	Thomann and Connolly, 1984
Lake Ontario	PCBs	lake trout	Connolly and Thomann, 1992
James River Estuary	Kepone	striped bass	Connolly and Tonelli, 1985
Hudson River Estuary	PCBs	striped bass	Thomann et al., 1989
New Bedford Harbor	PCBs, Cd, Cu, Pb	winter flounder, lobster	Connolly, 1991
Green Bay	PCBs	walleye, brown trout	Connolly et al., 1992; HydroQual 1995
Southern California Bight	PCBs, DDE	white croaker, kelp bass, Dover sole	HydroQual, 1994
Upper Hudson River	PCBs	largemouth bass	QEA, 1999

Model Overview

- Simulates a simplified representation of UHR food web
- Mechanistically and dynamically computes fish tissue PCB concentrations
- Accumulation of PCBs through all exposure routes (water, sediment, food)



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Theory and Basic Equations

- Accumulation in invertebrates
  - Biota-Sediment Accumulation Factor (BSAF)
    - Ratio of [PCB] in organism/[PCB] sediment or water column particulates

$$BSAF = \frac{v_L}{r_{soc}}$$

    - Converted to energy based BSAF to account for differences in energy density among prey and predators

$$BSAF_e = BSAF\left(\frac{f_L}{\lambda_{inv}}\right)$$

Theory and Basic Equations

- Accumulation in fish
  - Rate of change of chemical concentration in species *i*

$$\frac{dv_i}{dt} = K_{ui}c + \alpha_c \sum_{j=1}^{n} C_{ij}\, v_j - (K_i + G_i)v_i$$

Uptake directly from water

Uptake from feeding

Loss due to diffusion across the gill and growth dilution

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Accumulation in Fish

- Mass transfer at the gill
  - Contaminant uptake

$$K_u = \frac{k_{gl}}{k_{glO_2}} \frac{R}{c_{O_2}}$$

    - P-value = K_{gl}/k_{glO_2}

  - Gill elimination

$$K_{gill} = K_{ui} \nu_B = K_{ui} \left(\frac{1}{f_B + \pi_{LB} f_L} \right) \nu$$

Accumulation in Fish

- Bioenergetics
  - Growth and respiration rates used to calculate total energy requirement
    - Model computes growth rates based on age and weight

$$G = \frac{1}{W}\frac{dW}{dt}$$

    - Respiration rates

$$R = \beta W^{\gamma} e^{\rho T} c_{act}$$

    - Rate of energy usage

$$P_i = \lambda_o R_t + \left(\frac{W_{t+1}\lambda_{t+1} - W_t\lambda_t}{W_t}\right)$$

Accumulation in Fish

- Bioenergetics
  - Rate of consumption of food
    - Calculated from rate of energy usage

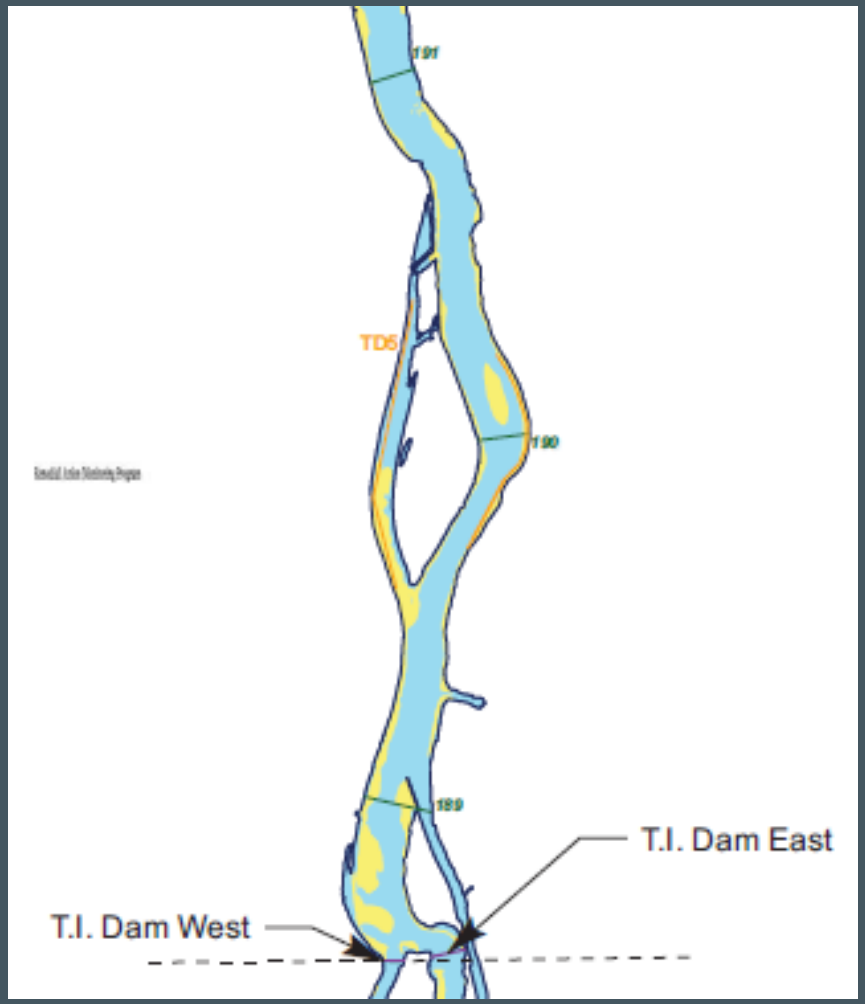
$$C_{ij} = f_{ij} \frac{1}{\lambda_j} \frac{P_i}{\alpha_F}$$

    - Rate of food consumption determines contaminant uptake from consumption of prey

$$\alpha_c \sum_{j=1}^{n} C_{ij} \nu_j$$

Application to UHR – Spatial Domain

- Parameterized and calibrated with site-specific data and fate model output from three UHR locations in:
  - Thompson Island (Reach 8)
  - Northumberland (Reach 6)
  - Stillwater Pools (Reach 5)

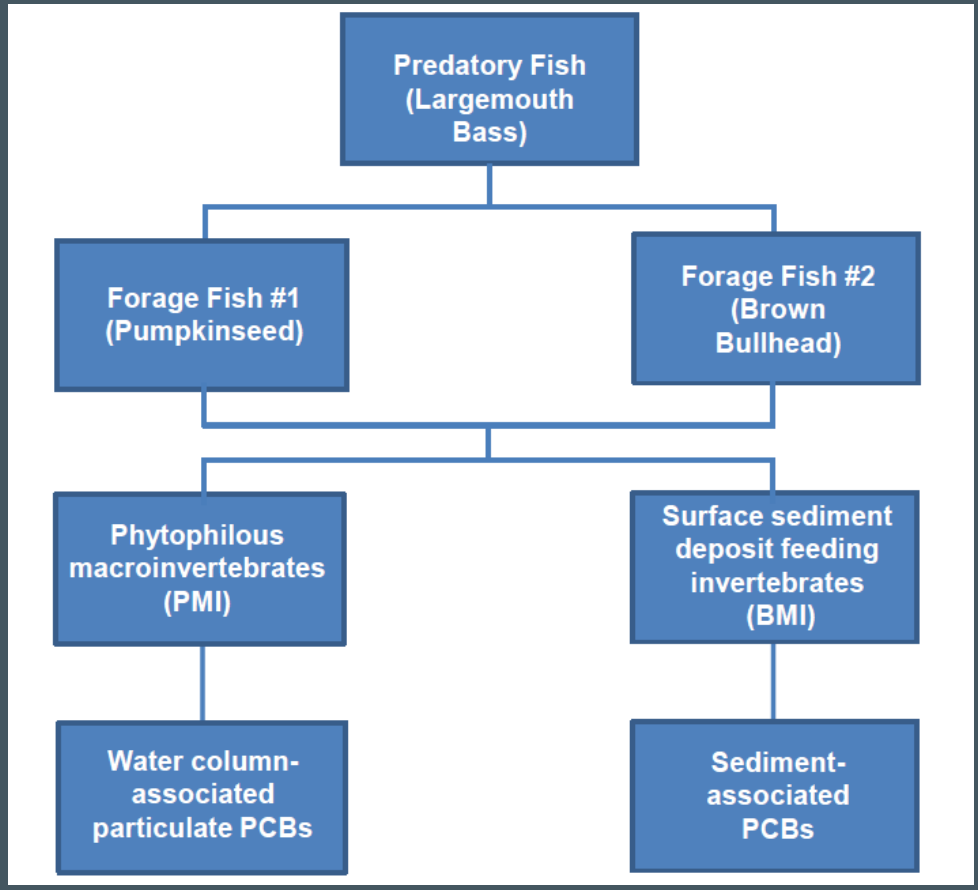


Application to UHR – Exposure Inputs

- Tri+ PCB fate model output
  - Water concentrations
    - Reach-wide averages
    - Dissolved and OC-based particulates
  - Sediment concentrations
    - OC-basis
    - Top 2 cm of sediment bed
    - Reach-specific averages of concentrations in model grid cells within fish habitat areas

Trophic Structure and Diet

- Four trophic levels
  - TL1 – Particulate matter
  - TL2 – Invertebrates (PMI and BMI)
  - TL3 – Forage fish (pumpkinseed and brown bullhead)
  - TL4 – Predatory fish (largemouth bass)



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Trophic Structure and Diet

- Relative proportion of PMI and BMI consumed by TL3 species

$$f_{Diet,i} = f_{Diet,PMI} f_{PMI,i} + (1 - f_{Diet,PMI}) f_{BMI,i}$$

Ratio of Benthic and Phytophilous Macroinvertebrates (BMI and PMI) in Fish Diets in the Bioaccumulation Model

	Brown Bullhead		Pumpkinseed	
	BMI	PMI	BMI	PMI
Thompson Island Pool	20	80	15	85
Northumberland Pool	45	55	15	85
Stillwater Pool	70	30	15	85

Trophic Structure and Diet

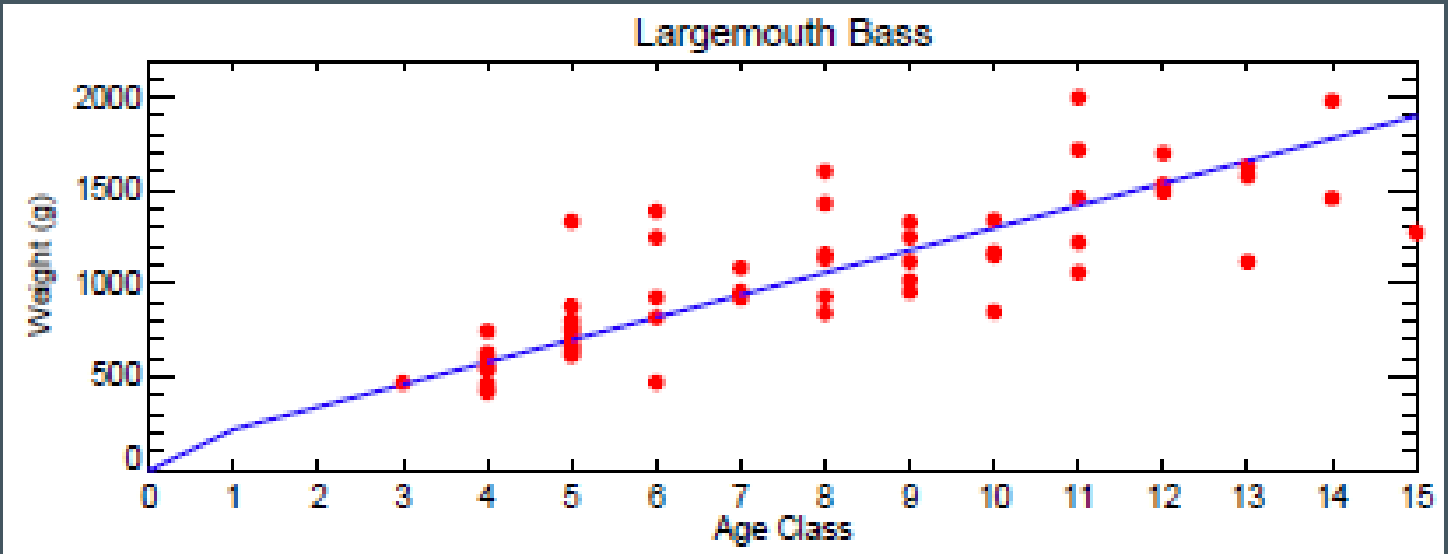
Largemouth bass diet varies with size and age

Age-Specific Diet of Largemouth Bass in the Model

Largemouth Bass	BMI	PMI	Pumpkinseed				Brown Bullhead				Largemouth Bass	
			Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4	Age 2	Age 3
Age 1	0.05	0.45	0.25				0.25					
Age 2			0.5				0.5					
Age 3			0.45	0.05			0.35	0.15				
Age 4			0.3	0.15	0.05		0.25	0.25				
Age 5			0.15	0.25	0.1		0.15	0.35				
Age 6			0.1	0.25	0.15			0.45			0.05	
Age 7			0.05	0.25	0.2			0.4	0.05		0.05	
Age 8				0.2	0.25	0.05			0.25			0.25
Age 9				0.15	0.25	0.1			0.25			0.25
Age 10-15				0.1	0.25	0.15			0.25			0.25

UHR Bioenergetics and Toxicokinetics

- Growth
  - Weight-Age relationships for fish
    - BMP data (2004 – 2008)
    - Average weights calculated for each age class and relationship smoothed visually



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UHR Bioenergetics and Toxicokinetics

- Lipid content
  - Annual weighted-harmonic means of BMP data for each location

$$H_{fl} = \frac{1}{\sum_{i=1}^{n} \frac{v_i}{\sum_{i=1}^{n} v_i} * \frac{1}{f_{l_i}}}$$

- Lipid/Blood partition coefficient
  - Congener concentration-weighted harmonic mean of $K_{ow} = 10^{5.81}$
- Contaminant assimilation efficiency = 0.8
- Gill exchange parameter
  - P-value = 0.25

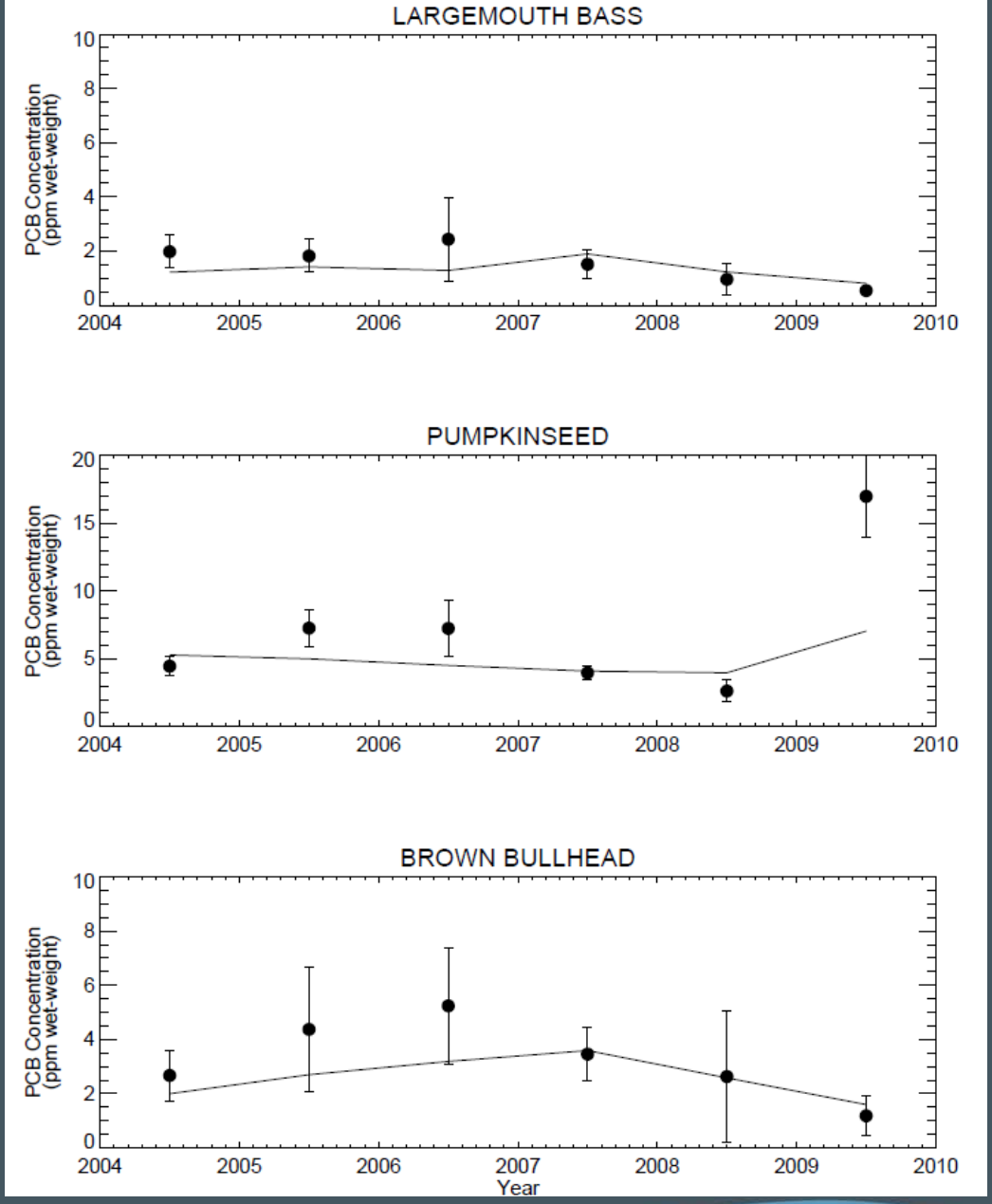
Bioaccumulation Model - Calibration

- Calibrated to total PCB concentrations in fish
  - 2004 – 2008 BMP data*
- Model results weighted by age-class proportions determined from BMP data
- Model results and data
  - Whole-body basis for pumpkinseed
  - Fillet basis for bass and bullhead

**Tri+ concentrations are on average 93% of total PCB concentrations based on available BMP congener data*

Calibration Results – TIP Wet-Weight Fish PCB Concentrations

See Figures 7-7 through 7-8 (UHR Modeling System Report) for calibration results at Northumberland and Stillwater



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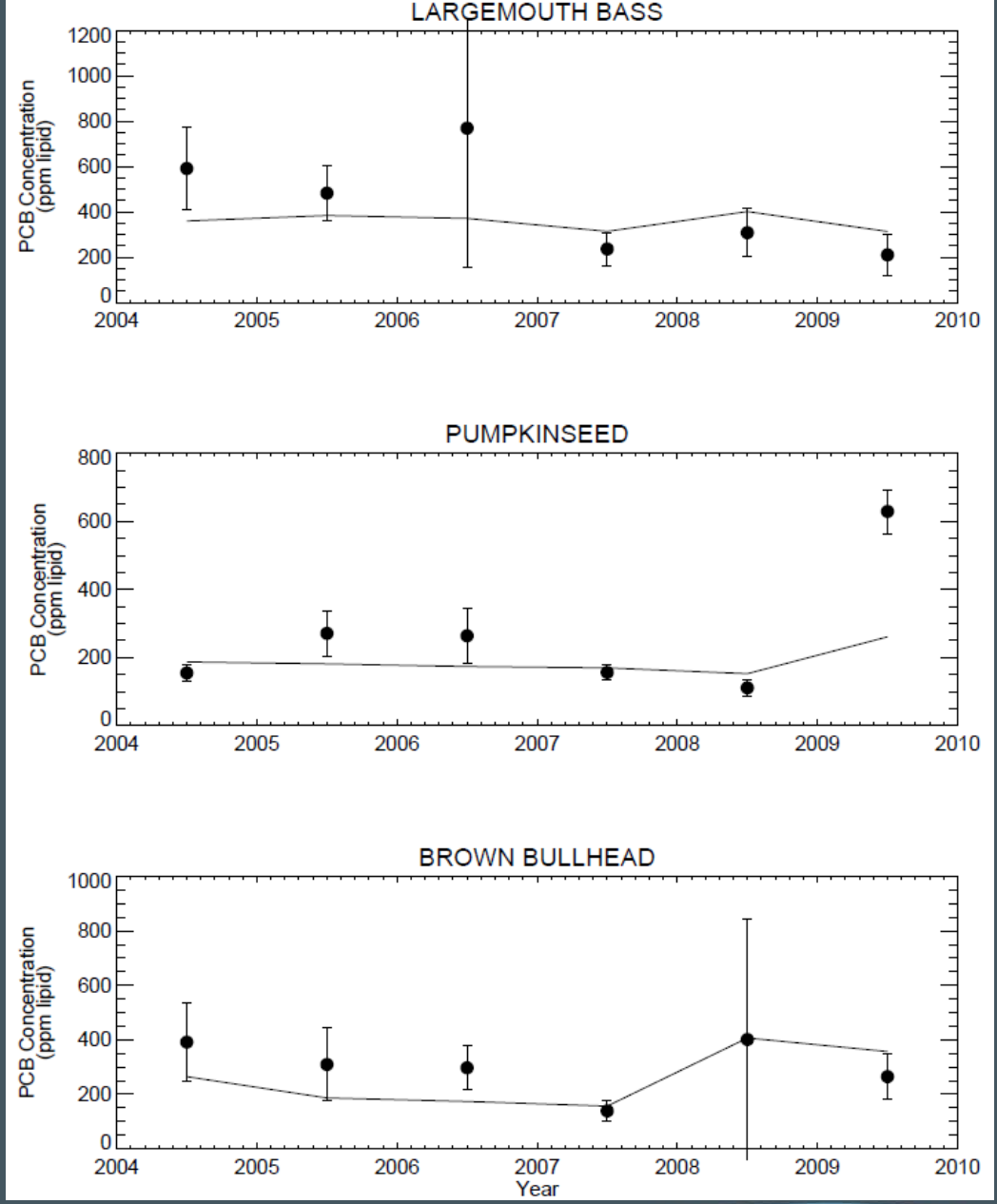
Calibration Results – TIP Lipid-Based Fish PCB Concentrations



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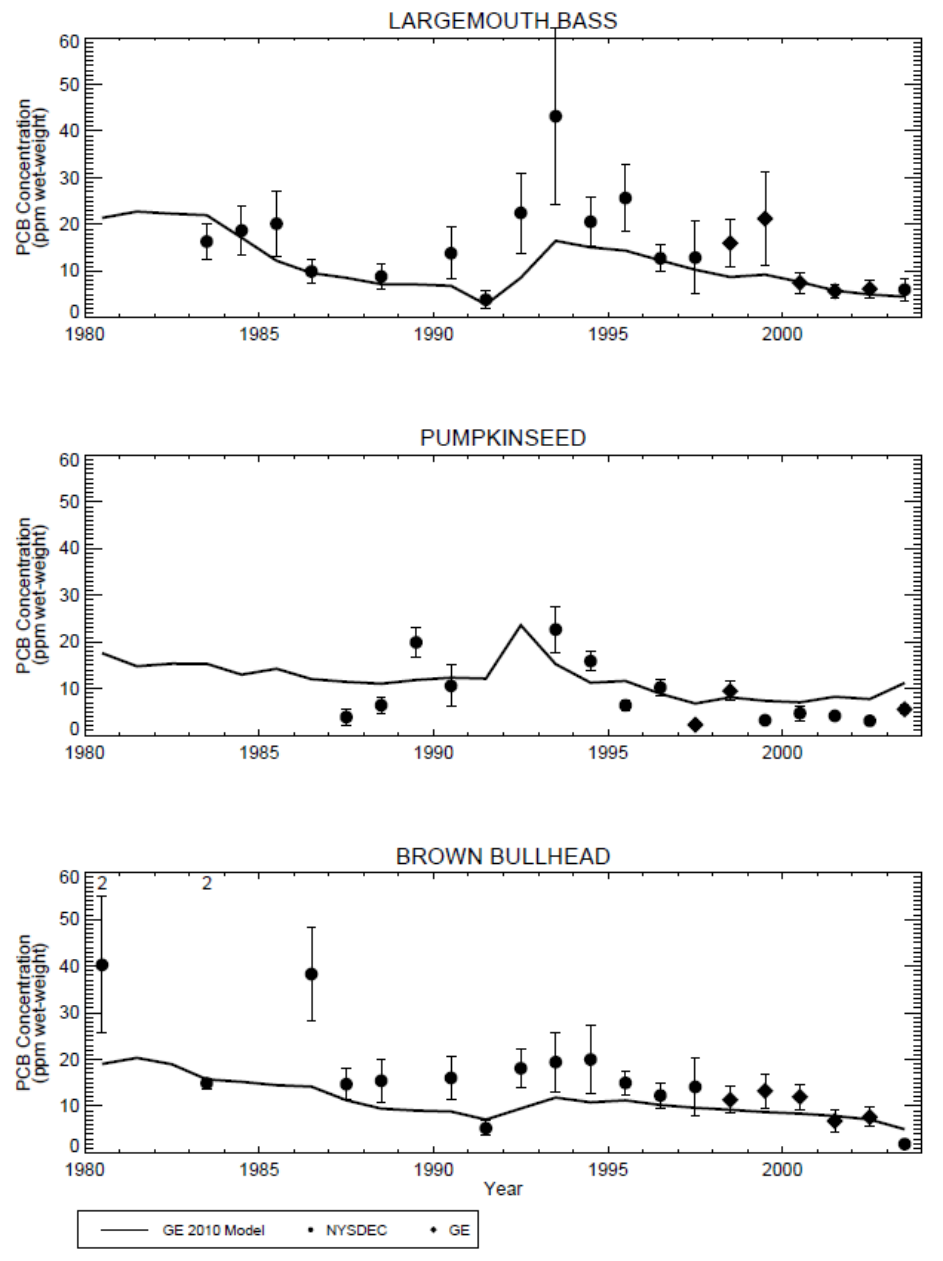
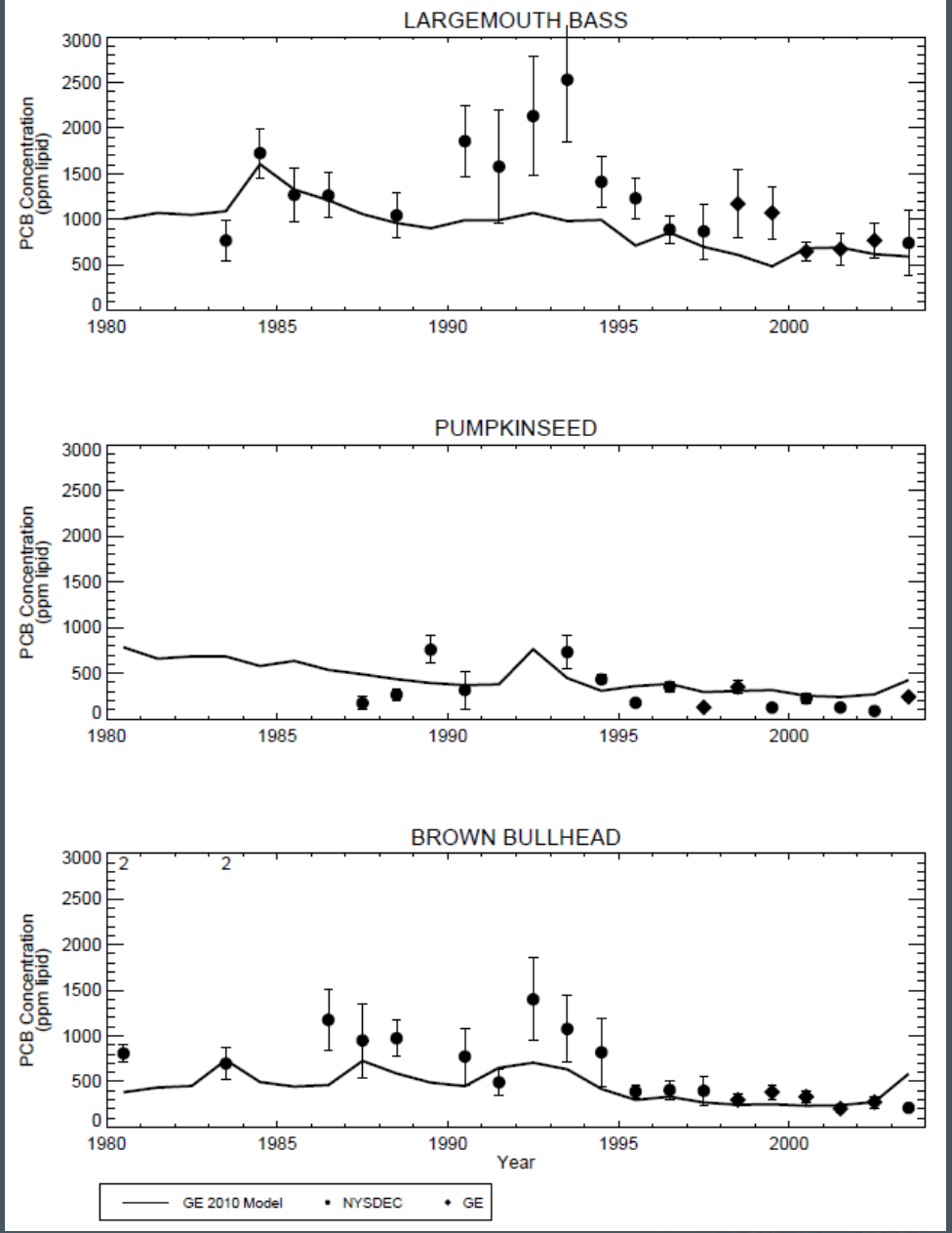
Bioaccumulation Model - Validation

- Model-to-data comparisons
  - Tri+ PCBs in TIP from 1980 through 2003
  - Lipid values were developed from NYSDEC HR biota monitoring program
- Results
  - Model provides reasonable representation (with the exception of fish PCB concentrations following Allen Mill event in 1991)

Validation Results – TIP Wet-Weight Fish PCB Concentrations



Validation Results – TIP Lipid-Based Fish PCB Concentrations



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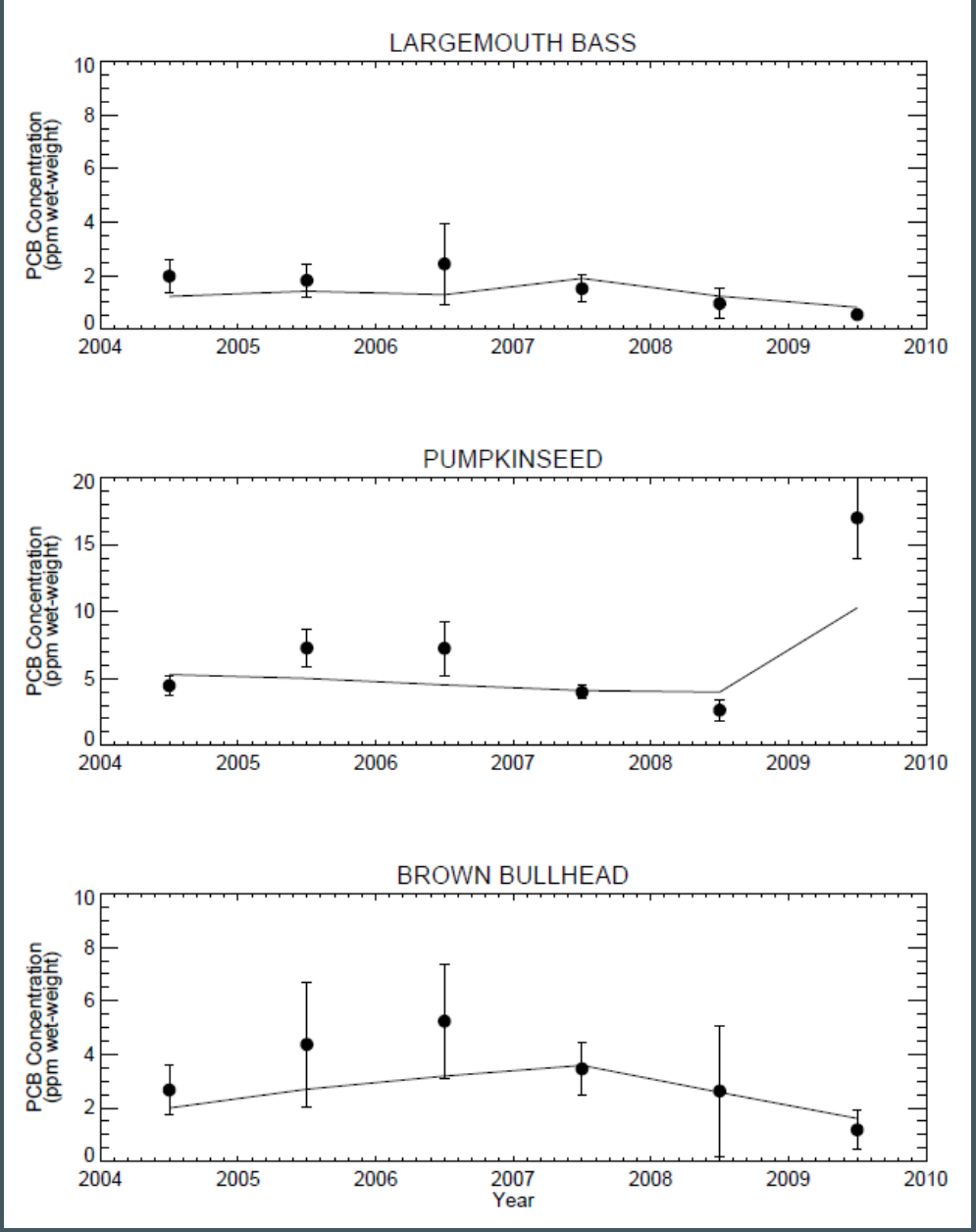
Modeling 2009

- Simulation using 2009 water column exposures
  - PCB concentrations from East Griffin Island Area as representative of TIP
  - Localized exposure resulted in an increased in modeled pumpkinseed PCB concentrations of approximately 3 mg/kg

Calibration with 2009 Results – TIP Wet-Weight Fish PCB Concentrations



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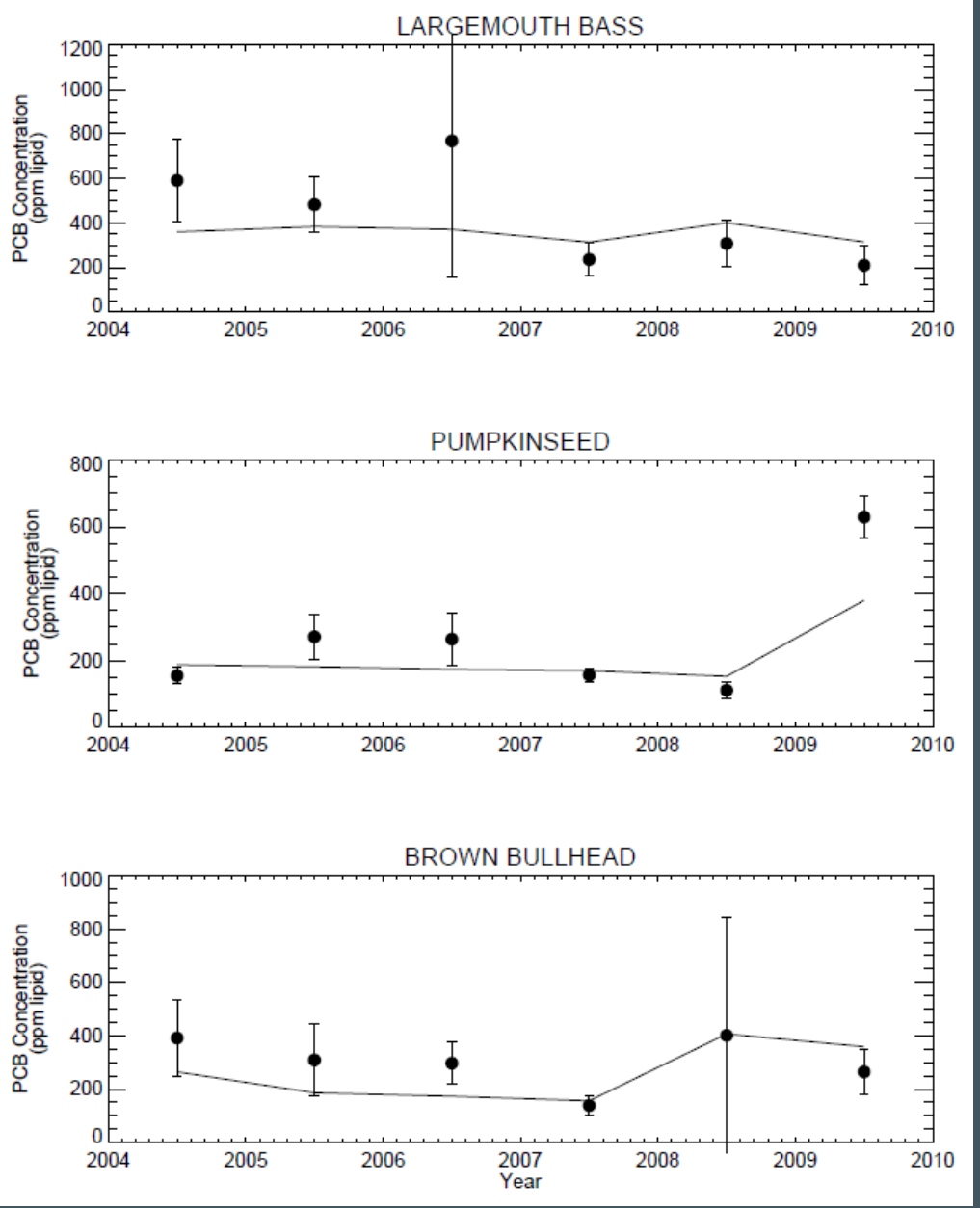
Calibration with 2009 Results – TIP Lipid-Based Fish PCB Concentrations



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Bioaccumulation Model - Conclusions

- Model successfully calibrated to observed fish tissue PCB concentrations in 2004 - 2008
- 1977 – 2003 model validation reasonable with the exception of the Allen Mill event
- Model validated during dredging in 2009 with the exception of pumpkinseed
  - Model under-predicted concentrations in pumpkinseed in TIP; good fit at Northumberland Pool, over-predicted at Stillwater